Neurocomputing 247 (2017) 165–172

Contents lists available at ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

Denoising and deblurring gold immunochromatographic strip images via gradient projection algorithms☆

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ARTICLE INFO

Article history:
Received 7 September 2016
Revised 19 February 2017
Accepted 22 March 2017
Available online 4 April 2017

Communicated by Bo Shen.

Keywords:
Lateral flow immunoassay
Gradient projection
Total variation
Image denoising
Image deblurring

ABSTRACT

Gold immunochromatographic strip (GICS) assay provides a quick, convenient, single-copy and on-site approach to determine the presence or absence of the target analyte when applied to an extensive variety of point-of-care tests. It is always desirable to quantitatively detect the concentration of trace substance in the specimen so as to uncover more useful information compared with the traditional qualitative (or semi-quantitative) strip assay. For this purpose, this paper is concerned with the GICS image denoising and deblurring problems caused by the complicated environment of the intestine/intrinsic restrictions of the strip characteristics and the equipment in terms of image acquisition and transmission. The gradient projection approach is used, together with the total variation minimization approach, to denoise and deblur the GICS images. Experimental results and quantitative evaluation are presented, by means of the peak signal-to-noise ratio, to demonstrate the performance of the combined algorithm. The experimental results show that the gradient projection method provides robust performance for denoising and deblurring the GICS images, and therefore serves as an effective image processing methodology capable of providing more accurate information for the interpretation of the GICS images.

1. Introduction

Gold immunochromatogr aphic strip (GICS) assay is a novel lateral-flow immunoassay format, where a colloidal gold-labeled antigen (or antibody) is especially used as the tracer. In recent years, the GICS assay has received substantial research attention for qualitative and semi-quantitative detection especially in the environment of resource-poor or non-laboratory. Applications of the GICS assays include testing of pathogens, drugs, hormones and metabolites in biomedical, phytosanitary, veterinary, feed/food and environmental settings. It has become clear that the GICS assay has merits such as ease of use, fast analysis speed, low cost, high sensitivity, good specificity, and satisfactory stability [16,18,21]. Owing to its attractive properties, the GICS has gained much research interest in the past few years, and the reported results can be generally classified into three categories. The first category is concerned with the promotion of the biochemical properties of the strips through material selection (see e.g. [8,10]). The second one is about establishing an effective mathematical model for lateral flow immunoassay so as to achieve superior strip performance which is of vital significance for qualitative analysis (see e.g. [17,25,26,28,29]). In the third category, the quantitative instruments of lateral flow immunoassay have been established and a great number of results have been available in the literature (see e.g. [4,5,7,9,11,12,20,24,27]).

Until now, most available approaches for developing quantitative instruments relate to the reflectance photometers for obtaining immunochromatographic strip signals. Therefore, the mechanical scanning equipments are always required in this

☆ This work was supported in part by the Natural Science Foundation of China under Grants 61403319 and 61673110, in part by the Fujian Natural Science Foundation under Grant 2015J05131, in part by the Fujian Provincial Key Laboratory of Eco-Industrial Green Technology, and in part by the Six Talent Peaks Project for the High Level Personnel from the Jiangsu Province of China under Grant 2015-DZXX-003.

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http://dx.doi.org/10.1016/j.neucom.2017.03.056
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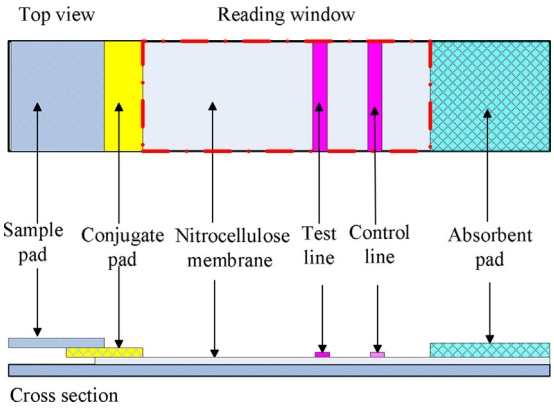

Fig. 1. The schematic structure of the gold immunochromatographic strip.

format and this might result in a long operation time as well as the bulky device, see e.g. [5,7,11]. Another alternative method is to develop image-based instruments that are not only computational efficient but also cost effective (see e.g. [4,9,12,20,24,27]), but the corresponding challenge is then to find out an appropriate image processing method. In this aspect, an efficient image denoising and deblurring algorithm is of essential significance to quantitative interpretation of the immunochromatographic strip for the following two reasons: (1) the background in the reading-window of the GICS image inevitably contains certain degree of noises on the strip which might be caused by the influences of temperature, humidity as well as the non-uniform penetration of liquid and colloidal gold; and (2) the acquired GICS image always has a blur problem due to the different thickness of nitrocellulose membranes of the gold immunochromatographic strips. In search of an efficient image denoising and deblurring approach, the combination of the gradient projection method and the total variation minimization approach appears to be an ideal candidate for denoising and deblurring the GICS images after segregating the reading-window from the GICS images extracted by the canny operator and mathematical morphology method.

In 2009, Beck and Teboulle firstly proposed the gradient projection algorithms in [1] for solving the image denoising and deblurring problems on the basis of the discretized total variation (*TV*) minimization method under the constraints. The total variation was first introduced by Rudin–Osher and Fatemi (ROF) in [19] to treat image denoising problem with a *TV*-regularized minimization framework and has proven to be effective when applied to an extensive range of applications in image processing. The gradient-based algorithm provides a brilliant simplicity as well as a remarkable global convergence rate owing to the combined use of the fast iterative shrinkage/threadsholding algorithm (FISTA) [2] within the *TV*-regularized minimization framework. So far, despite its great application potential, the gradient-based algorithm has not yet been considered in GICS image processing, and the main purpose of the paper is therefore to fill the gap by looking into how the gradient-based algorithm can be exploited to denoise and deblur the GICS images.

One thing to note here, the GICS images themselves exhibit the following distinguishing characteristics, which increase difficulties of the processing procedure. Firstly, main attention is paid to the GICS reading-window that including the test and control lines on the nitrocellulose membrane so as to promote the efficiency and effectiveness. Therefore, it is necessary to acquire the reading-window by segmentation operation. Secondly, the phenomena of blurring, uncertainty, and mixture with background may appear on the test and control lines, since the strips are generally made/smeared by a roller in a non-uniform manner. Moreover, with the adding of the test liquid (e.g. urine, blood, serum), lots of interference signals might be simultaneously brought on the strip. With expectation to address the above identified complexities, we devote to examine whether and how the gradient projection algorithm, together with the total variation minimization method, can be utilized for achieving the GICS image denoising and deblurring. We endeavor to show that the presented algorithm is indeed an effective image processing approach for analysing gold immunochromatographic strip.

The primary contributions of this paper are mainly twofold. *(1) The gradient projection algorithm combined with the total variation minimization method is proven to be robust yet effective in accurately denoising and deblurring GICS images through quantitative performance evaluation in terms of the peak signal-to-noise ratio. (2) The results show that the presented denoising and deblurring algorithm gives rise to highly accurate information that is of importance for the segmentation and the feature parameter calculation, and thus serves as an innovative image method for interpretation of gold immunochromatographic strip.* The structure of this paper is arranged as follows. In Section 2, the gold immunochromatographic strip assay is introduced. The gradient projection method as well as total variation minimization framework for denoising and deblurring images is depicted in Section 3. In Section 4, the results of image denoising and deblurring by the presented approach are discussed, meanwhile the overall performance is also illustrated. In the end, concluding remarks are summarized in Section 5.

2. The gold immunochromatographic strip image and problem formulation

Gold immunochromatographic strip utilizes the techniques of colloidal gold labeling and chromatography (Fig. 1). Typically, the design of immunochromatographic strip is on the basis of the specific reaction of antigen and antibody. In this paper, main attention is paid to the sandwich format of GICS where one antibody is immobilized on the nitrocellulose membranes or other solid carrier, while the other antibody is labeled with colloidal gold. And the labeled antibody is dried on a piece of low protein binding material in conjugate pad. When the specimen passes through and rewet the material that is dried with the antibody conjugate, it will release the antibody conjugate. If the sample contains the antigen to be detected, the antigen will react with antibody conjugate and form an antigen–antibody conjugate compound. The compound continues to move by capillary action to the membrane where the capture antibody is embedded. The antibody will capture the antigen–antibody conjugate to form a sandwich type compound. This sandwich type compound will stay on the membrane

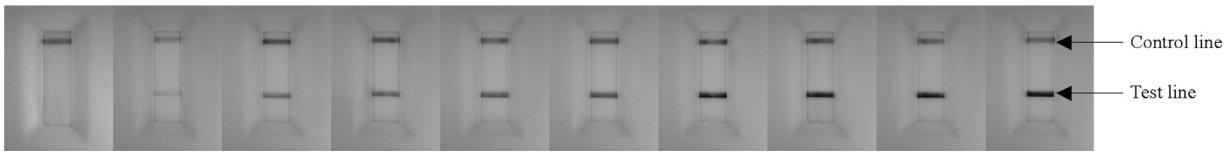

Fig. 2. Images of gold immunochromatographic strip with different concentration(from the left side: 0, 10, 35, 75, 100, 150, 200, 300, 400, 500 mIU/ml).